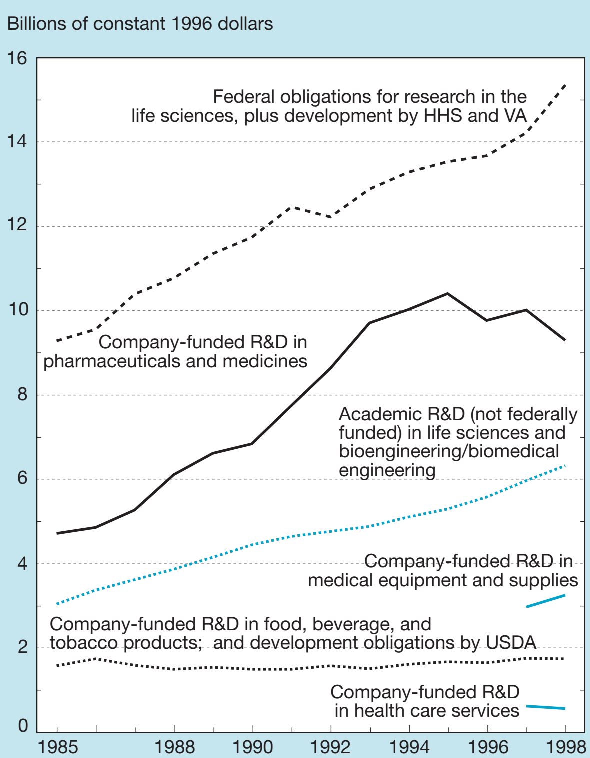
tures in this category grew from $6.6 billion in 1985 to $8.8 billion in 1998, although the sector has displayed considerable year-to-year fluctuation between 1996 and 1998 (inclusive). The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering declined between 1985 and 1998, from $1.2 to $980 million (in constant 1996 dollars). Academic R&D (not federally funded) in chemistry and chemical engineering, the smallest category, grew steadily in real terms, from $237 million in 1985 to $444 million in 1998.

R&D in Life Sciences. The broad life sciences field accounted for $36.5 billion of R&D in 1998 (in constant 1996 dollars). R&D in this area is characterized by strong and fairly continuous real growth in its three largest categories. (See figure 4-16.) The largest of these three, Federal obligations for research in the life sciences, plus development expenditures by HHS and the Department of Veterans Affairs, rose from $9.3 billion in 1985 to $15.4 billion in 1998 in constant 1996 dollars. Company-funded R&D in pharmaceuticals and medicines grew dramatically in real terms, from $4.7 billion in 1985 to $10.4 billion in 1995 but then declined to $9.3 billion by 1998. In contrast, academic R&D (not federally funded) in life sciences and bioengineering/biomedical engineering grew continuously, from $3.0 billion in 1985 to $6.3 billion in 1998.

Figure 4-16.
R&D associated primarily with life sciences



HHS = Department of Health and Human Services; USDA = U.S. Department of Agriculture; VA = Department of Veterans Affairs

See appendix table 4-29.

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With regard to food and other traditional products, however, company-funded R&D in food, beverage, and tobacco products, and development expenditures by USDA, show virtually no real R&D growth. That is, as shown in figure 4-16, R&D for this combined subcategory grew only from $1.6 to $1.7 billion between 1985 and 1998. Finally, two new categories of industrial R&D in the life sciences, arising from the new NAICS classification system, are company-funded R&D in health care services and company-funded R&D in medical equipment and supplies. In 1998, the former accounted for $566 million in R&D and the latter for $3.3 billion, in constant 1996 dollars.

Research Alliances: Trends in Industry, Government, and University Collaboration

All major players involved in the creation, diffusion, and commercialization of R&D have experienced changes in how innovation activities are financed, organized, and performed (Jankowski 2001a; Mowery 1998). Well-known risks of conducting scientific research and commercializing its results have been compounded by the increased speed and interdisciplinary nature of technological developments. In this environment, collaborations and alliances, at home or overseas, allow partners to share R&D costs, pool risks, and enjoy access to firm-specific know-how and commercialization resources (Hagerdoon, Link, and Vonortas 2000; Vonortas 1997). In the policy arena, changes in antitrust regulations, intellectual property policy, and technology transfer have fostered a new setting for collaborative research since the early 1980s. (See sidebar, "Major Federal Legislation Related to Cooperative R&D and Technology Transfer.") These changes have paralleled policy and market trends in other advanced economies, contributing to a national and global economy increasingly dependent on knowledge-based competition and networking.

Joint research activities complement other tools to acquire or develop technology, from licensing off-the-shelf technologies to mergers and acquisitions (M&A). Corporate R&D planning increasingly requires a combination of technology exchange (acquisition of external R&D outputs as well as spinoff of noncore technologies) and strategic R&D alliances to excel in innovation and market performance (Arora, Fosfuri, and Gambardella 2000).[25] Even local and Federal Government agencies have developed technology strategies to maximize regional competitive advantage and national benefits. Universities also have adjusted to this new environment by increasing funding links, technology transfer, and collaborative research activities with industry and Federal agencies over the last two decades.

At the same time, collaborative networks are not without risks. Unintended transfer of proprietary technology is always a concern for businesses. Cultural differences among differ-

[25]M&A activity and international R&D investments are covered in a separate section below.

Major Federal Legislation Related to Cooperative R&D and Technology Transfer

- **Stevenson-Wydler Technology Innovation Act (1980)**—required Federal laboratories to facilitate the transfer of federally owned and originated technology to state and local governments and to the private sector.
- **Bayh-Dole University and Small Business Patent Act (1980)**—permitted government grantees and contractors to retain title to federally funded inventions and encouraged universities to license inventions to industry. The act is designed to foster interactions between academia and the business community.
- **Small Business Innovation Development Act (1982)**—established the Small Business Innovation Research (SBIR) program within the major Federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies.
- **National Cooperative Research Act (1984)**—encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.
- **Federal Technology Transfer Act (1986)**—amended the Stevenson-Wydler Technology Innovation Act to authorize cooperative research and development agreements (CRADAs) between Federal laboratories and other entities, including state agencies.
- **Omnibus Trade and Competitiveness Act (1988)**—established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The act created the Advanced Technology Program and the Manufacturing Technology Centers within NIST to help U.S. companies become more competitive.
- **National Competitiveness Technology Transfer Act (1989)**—amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- **National Cooperative Research and Production Act (1993)**—relaxed restrictions on cooperative production activities, enabling research joint venture participants to work together in the application of technologies they jointly acquire.
- **Technology Transfer Commercialization Act (2000)**—amended the Stevenson-Wydler Act and the Bayh-Dole Act to improve the ability of government agencies to license federally owned inventions.

ent industries, academic or government partners, or international collaborators present additional difficulties for managing alliances. On the other hand, the degree of cohesion among members may bring unintended anticompetitive behavior or may conflict with other economic or science policy objectives. For example, industry-university and industry-government collaborations have highlighted concerns about adequate availability of research findings in certain scientific areas.[26]

Types of Research Partnerships

Collaborations can be classified and analyzed according to several criteria. By type of members, there are a variety of business, university, and government combinations, including government-to-government technical collaborations. In terms of activities, business alliances may focus on manufacturing, services, marketing, or technology-based objectives. For example, according to an OECD paper, R&D alliances represent as many as 23 percent of all types of alliances in North America compared with 14 percent in Western Europe and 12 percent in Asia (Kang and Sakai 2000). Also according to this study, North America is the only region in which the share of R&D alliances is higher than the share of manufacturing alliances.

Technology-based collaboration broadly defined includes joint research activities, technology codevelopment, contract research, and technology exchange (licensing and cross-licensing). In particular, strategic research partnerships (SRPs), a subset of these broad interactions, emphasize joint R&D activities as opposed to contract research or other exclusively financing or exchange transactions. SRPs can take the form of formal joint ventures (a specific term in many legal codes internationally) or more informal agreements. Types of SRPs found in available databases and published studies include research joint ventures (RJVs), cooperative R&D agreements, and strategic technology alliances.

According to Hagerdoon, Link, and Vonortas (2000), in the early 1970s the majority of research partnerships were equity-based research corporations, but "[b]y the mid-1990s, more than 85 percent of research partnerships did not involve equity investments." This is attributed in large part to the higher degree of organizational flexibility of nonequity agreements. Still, SRPs of any type constitute a highly flexible tool for pursuing new technology venues. A relatively small participation in any one alliance may bring the full benefits of the research outputs, which may be further developed or commercialized. Furthermore, these partnerships may evolve into other types of agreements or acquisitions, or they may serve as an entry into new geographic markets over time.

Dedicated databases tracking these developments and sponsored in part by NSF include the Cooperative Research (CORE) database, the National Cooperative Research Act (NCRA)-RJV database, and the Cooperative Agreements and Technology Indicators database compiled by the Maastricht

[26]For an overview of the issues, see Behrens and Gray (2001); Feldman et al. (2001); Brooks and Randazzese (1998); and Cohen et al. (1998).

Economic Research Institute on Innovation and Technology (CATI-MERIT) (Link and Vonortas 2001). The first two cover U.S.-based alliances recorded in the *Federal Register,* pursuant to the provisions of NCRA.[27] Trends in either database are illustrative only of the technical and organizational characteristics of joint ventures in the United States because the registry is not intended to be a comprehensive count of cooperative activity by U.S.-based firms. The CATI-MERIT database covers international collaborations based on announcements of alliances and tabulated according to the country of ownership of the parent companies involved.[28]

Domestic Public and Private Collaborations, Including Federal Programs

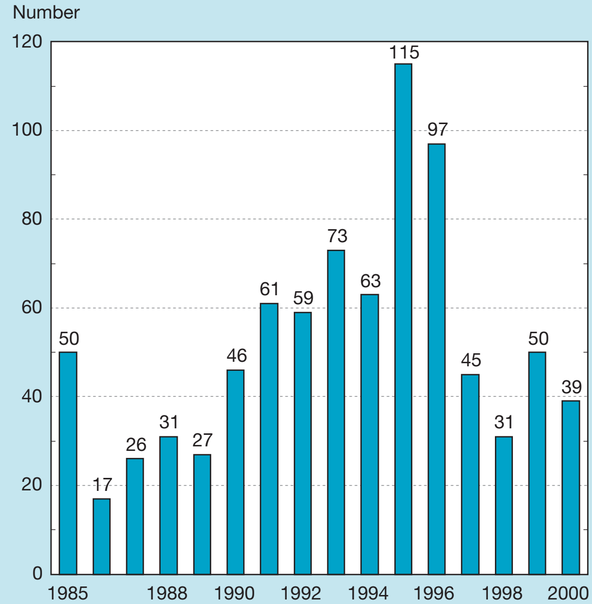
Research Joint Ventures

More than 800 RJVs were registered in the NCRA-RJV database from 1985–2000.[29] According to Vonortas (2001), from 1985 to 1999 these collaborations involved more than 4,200 unique businesses and organizations. Of these participating organizations, more than 3,000 (about three-fourths) were U.S. based; 88 percent of these domestic participants were for-profit firms, 9 percent were nonprofit institutions (including universities), and 3 percent were government units. Two-thirds of the organizations represented in these alliances participated in only one collaboration over the 15-year period ending in 1999; another 27 percent participated in two to five alliances.

The CORE database (Link 2001), based on collaborations as a unit, shows the following trends:

- In 2000, there were 39 new RJVs compared with 50 in 1999. New filings peaked in 1995 at 115 after increasing successively since 1986. (See figure 4-17.) Brod and Link (2001) estimated a statistical model to explain the trends in RJVs filings, including the decline since the 1995 peak. They find that filings are likely to be countercyclical. In particular, they argue that "[w]hen the economy is strong and…R&D is growing, firms may rely less on cooperative research arrangements…than when the economy is weak and internal resources are more constrained."

Figure 4-17.
Domestic research joint ventures: 1985–2000



NOTE: Data are annual counts of new research joint ventures registered under the National Cooperative Research and Production Act.

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database.* Report submitted to the National Science Foundation, Arlington, VA.

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- Half of the research joint ventures in 1985–2000 involved companies in three industries: electronic and electrical equipment (148 of 829, or 18 percent), communications (135, or 16 percent), and transportation equipment (127, or 15 percent).

In terms of the composition of these joint ventures, petroleum refining (SIC 29) and related oil and gas extraction each had a median of eight members, the highest among individual industries over 1989–99. Chemicals (SIC 28) and electronic and electrical equipment and components (SIC 36) had a median of six and five, respectively.[30] Participation of universities and Federal agencies in these colaborative activities is discussed next.

[27]Domestic data come from *Federal Register* filings of RJVs. Restrictions on multifirm cooperative research relationships were loosened by NCRA in 1984 (Public Law 98-462) after concerns over the technological leadership and international competitiveness of American firms in the early 1980s. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. However, to gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with the Department of Justice. In 1993, the National Cooperative Research and Production Act (NCRPA, Public Law 103-42) extended legal protection to collaborative production activities.

[28]The CATI database is compiled by the Maastricht Economic Research Institute on Innovation and Technology in the Netherlands. The data consist of thousands of interfirm cooperative agreements. These counts are restricted to strategic technology alliances, such as joint ventures for which R&D or technology sharing is a major objective, research corporations, and joint R&D pacts. CATI is a literature-based database. Its key sources are newspapers, journal articles, books, and specialized journals that report on business events. Because data are limited to activities publicized by the firm, agreements involving small firms and certain technology fields are likely to be underrepresented. Another limitation is that the database draws primarily from English-language materials.

[29]Note that data from the *Federal Register,* while illustrative, are based on a specific legislative intent focused on antitrust concerns, as opposed to a dedicated survey activity. This fact may bias the RJVs counts and/or their composition in several ways. In one respect, the counts may fall short of the true extent of the phenomenon depending on the (perceived) antitrust climate over time. On the other hand, some joint ventures may register an excessive number of members, even if actual research activity is limited to few R&D active partners.

[30]In some SICs, the average number of members is inflated by several consortia with as many as several hundred members. These large groupings may not represent actual collaborative research activity but agreements to share results by providing funding, facilities, or other type of support, while joining a legally sanctioned umbrella. In particular, there are at least 19 consortia with more than 100 members in this database, many of which have multiple university members, as well as government participation.

Public-Private Collaborations

Collaborative S&T activities may involve public institutions, such as government agencies and universities, as well as other nonprofit research organizations. Activities include transfer of technology from Federal laboratories and universities, small business S&T programs, and the Advanced Technology Program. See sidebar, "The Advanced Technology Program: 1990–2000 Trends."

Federal Technology Transfer Programs. In general, technology transfer can be defined as the exchange or sharing of technology or technical knowledge across different organizations. It can take place in a number of scenarios: in public or private research collaborations (the focus of this section), in fee-based transactions (licensing and trade), and in training or hiring activities. The role of Federal agencies and laboratories, either as a source of technology to be commercialized by private parties or as a research partner, is considerable given substantial Federal R&D activity, as described earlier in the chapter. Public policy objectives for Federal cooperative research and technology transfer activities include the support of mission objectives such as defense, public health, and the promotion of competitiveness and economic growth (Bozeman 2000). One common technology transfer mechanism is a license that confers rights to exploit commercially a patented or otherwise proprietary technology. Other technology transfer mechanisms include cooperative agreements, personnel exchange, user facility agreements, and technical assistance.

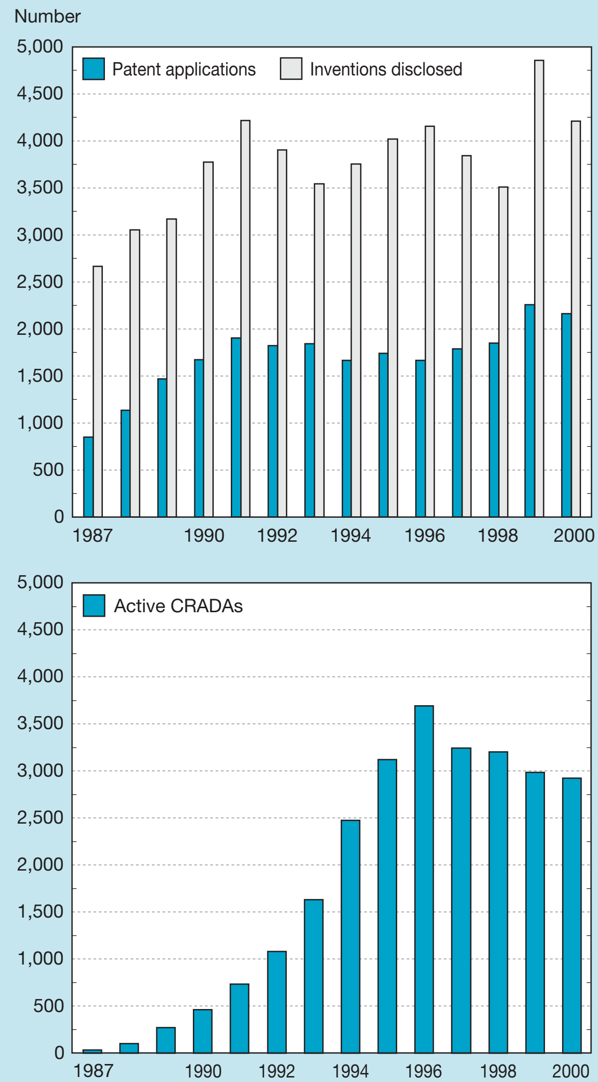
In the early 1980s, Federal technology transfer became widely regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. The Stevenson-Wydler Technology Innovation Act of 1980 added technology transfer of Federally-owned or originated technology as an explicit mission of Federal laboratories. In the same year, the Bayle-Dole Act specified the authority of Federal agencies to obtain patents, grant licenses, and transfer custody of patents with the explicit purpose of promoting the utilization and marketing of inventions under Federally-funded R&D by nonprofit organizations and small businesses. Subsequent amendments repealed the restriction to grant an exclusive license only to small firms (Schacht 2000). Later in the decade, the Federal Technology Transfer Act of 1986 authorized government-owned and government-operated laboratories to enter into Cooperative Research and Development Agreements (CRADAs)[31] with private industry and gave all companies, regardless of size, the right to retain title to inventions (Schacht 2000). The 1989 passage of the National Competitiveness Technology Transfer Act extended this authority to contractor-operated labs (including DOE's FFRDCs). More recently, the Technology Transfer Commercialization Act of 2000 (Public Law 106-404) improved the ability of Federal agencies to license federally owned inventions.

[31]The statute defines CRADAs as any agreement between one or more laboratories and one or more non-Federal parties in which the government shares personnel, facilities, equipment, or other resources (but not funding) with non-Federal parties for the purpose of advancing R&D efforts consistent with the missions of the laboratories.

Data on technology transfer activities from Federal agencies are reported to the Department of Commerce and include inventions disclosed, Federally-owned patents, licenses of patented inventions, income from those patented inventions, and the number of CRADAs. In 2000, Federal agencies involved in R&D and technology transfer activities reported 4,209 invention disclosures, 2,159 patent applications, and 1,486 patents issued. (See figure 4-18 and appendix table 4-35.) Since fiscal year 1997, a total of 5,655 patents have been issued to Federal agencies.

A total of 2,924 CRADAs involving 10 Federal agencies and their laboratories were active in 2000. The largest participants by far are DOD laboratories (1,364 active CRADAS or 47 percent of the total) and DOE (687 or 23 percent). The number of active CRADAs increased rapidly in the early and

Figure 4-18.
Federal technology transfer indicators: 1987–2000



CRADA = Cooperative Research and Development Agreement

See appendix table 4-35.

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The Advanced Technology Program: 1990–2000 Trends

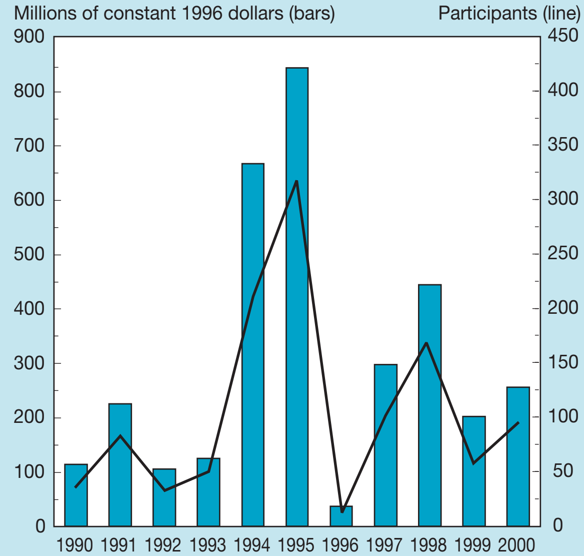
The Advanced Technology Program (ATP), National Institute of Standards and Technology, U.S. Department of Commerce, has funded the development of high-risk enabling technologies since 1990. Proposals are submitted to a peer review process based on technical and economic criteria. Awards are made on a cost-share basis for both single applicants and joint ventures.

During the 1990–2000 period, over 1,100 companies, nonprofit institutions, and universities participating in the program received $3.3 billion in R&D funding—divided about equally between ATP and industry funds. (See appendix table 4-38.) These participants pursued 522 projects in five technology areas: biotechnology, electronics, information technology, advanced materials and chemistry, and manufacturing. In terms of project structure, 350 projects (67 percent) were single-company projects and 172 (33 percent) were joint ventures; 812 participants (70 percent) were members of joint ventures over this 11-year period.

In 2000, funding for projects increased 27 percent to $256 million in constant 1996 dollars after declining more than 50 percent in 1999. (See figure 4-19.) The funding in 2000 included $135 million (53 percent) from ATP and $122 million (47 percent) from industry. At the same time, the number of awards increased 46 percent to 54, whereas the number of participants increased by 67 percent. Funding for the ATP program peaked in the last two years of the first Clinton administration, declined drastically in 1996, and has ranged between one-fourth and one-third of the 1995 peak ever since.

The ups and downs in ATP funding over the 1990s reflect, in part, an ongoing debate over the program's goals. On one hand, the inherent technical and market risks and the inability of private firms to fully capture the benefits in some enabling technologies are recognized by most observers as generating underinvestment in certain R&D areas. However, the role and effectiveness of ATP and similar technology partnership programs as policy tools to answer this challenge are still under debate.* At the time of this writing, the Bush administration's FY 2002 budget calls for the suspension of new awards and for an evaluation of the program to assess long-term funding (U.S. OMB 2001b).

Figure 4-19.
ATP funding and number of participants: 1990–2000



ATP = Advanced Technology Program

NOTE: Constant dollars based on fiscal year GDP implicit price deflators (appendix table 4-1).

See appendix table 4-38.

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*For empirical studies related to this debate see David, Hall, and Toole (2000). For public policy analysis of the program, see Wessner (2001) and references therein.

mid-1990s, reached a peak of 3,688 in fiscal year 1996, and stabilized around 3,000 since. (See figure 4-18.) For a comprehensive review of licensing and other policy issues in CRADAS using data on the above indicators to fiscal year 1998, see U.S. OTP (2000). Other data on CRADAs such as internal structure (membership profiles, organizational structure), activities, and research outputs (licensing, commercial and agency mission impacts) have been explored by a number of case studies but are unavailable from more comprehensive survey data.[32]

Industry-University Collaboration. Even though the Federal Government still provides the bulk of university research funding, universities have adjusted to the decreasing role of the Federal Government in R&D funding by relying increasingly on non-federal funding sources[33] and by engaging in collaborations with nonacademic organizations (Jankowski 1999). Universities have also increased their patenting and technology transfer activities, notably since the Bayh-Dole Act of 1980 (and subsequent amendments) allowed them to patent federally funded research (Mowery et al. 2001; Nelson 2001).[34] From the perspective of industry, joint research activities with academia support industrial research objectives and comple-

[32]See Mowery, David, C. *Using Cooperative Research and Development Agreements as S&T Indicators: What Do We Have and What Would We Like?* in NSF (2001g) and references therein.

[33]For a discussion of funding of academic R&D in the U.S. and other advanced economies, see "International Comparisons of National R&D Trends" later in the chapter.

[34] For more on university patenting activity and technology transfer see 'Outputs of Scientific and Engineering Research' in Chapter 5, Academic Research and Development, of this volume. See also the special issue of the *Journal of Technology Transfer* on the Symposium on University-Industry Technology Transfer (vol. 26, no. 5, January 2001).

ment other aspects of industry-university relations, including most notably the hiring of graduates.

Federal assistance for cooperative research centers between industry and academia, including NSF's Cooperative Research Centers, was specified in the Federal Technology Transfer Act of 1986.[35] A paper based on a survey of NSF's Industry-University Cooperative Research Centers (IUCRCs) suggests that these centers have had a positive impact on joint authorship with university scientists, contract research, licensing of university patenting, and hiring of graduate studies (Adams, Chiang, and Starkey 2001).

The CORE database on research alliances (described earlier) provides some indication of the extent of these public-private collaborations. For the 1985–2000 period, universities participated in 15 percent of these RJVs, and 11 percent had at least one Federal laboratory member. However, eight percent of domestic alliances had at least one university as a research member in 2000, down from 16 percent in 1999 and below the 30 percent peak in 1996.

From 1985–2000, 30 percent of RJVs in electronic and electrical equipment (SIC 36) and 19 percent of industrial machinery RJVs (including computer manufacturing) had at least one U.S. university as a partner, topping all industries in this category (see figure 4-20). Collaborations in these two industries also had the highest level of participation by Federal laboratories.

Small Business S&T Programs. Small businesses have a long-recognized role in fostering local and national economic growth. In the S&T arena, this recognition translates into the effort to increase the participation of small business in Federal R&D and technology transfer. Although economic activity and R&D performance tend to be performed by large firms in the manufacturing sector and small firms in the nonmanufacturing sector, as discussed earlier in the chapter, economists have debated over the years whether smaller or larger firms are more likely to engage or succeed in innovative activities. Further studies have shown that their relative incentives and efficiencies in research and commercialization depend on a number of institutional and technological characteristics over the life cycle of products or industries. Furthermore, alliances between small or startup firms and established companies may fare better than either type of business individually.

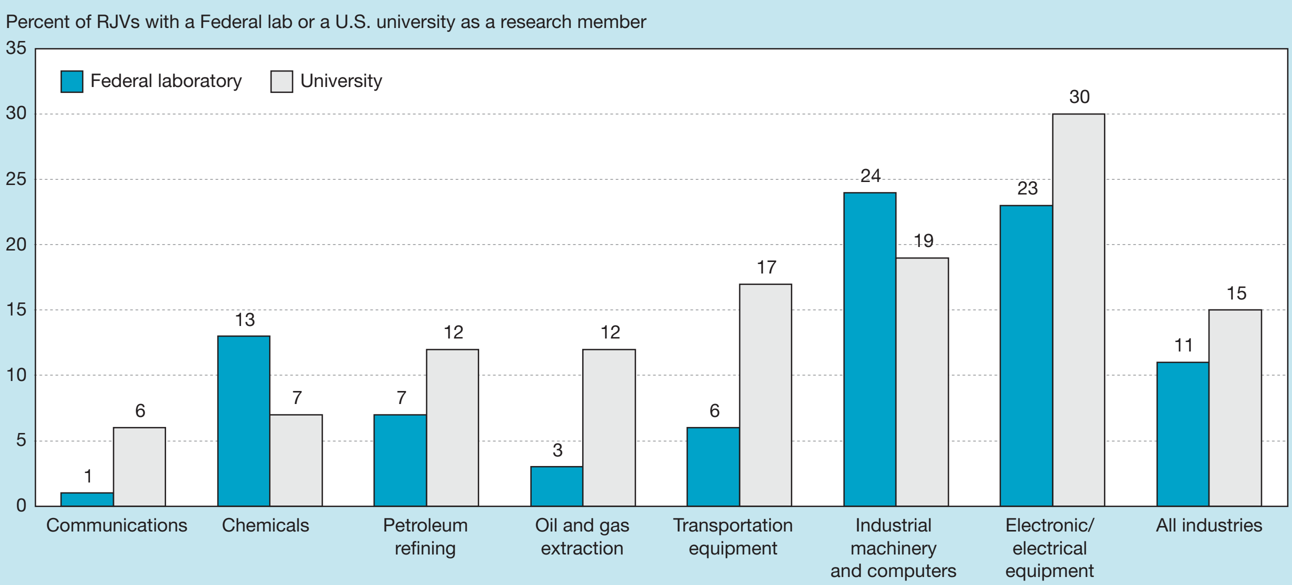
Nevertheless, smaller firms are more likely than larger or more established companies to be affected by a number of financing and other market constraints. Internal funds have been shown to significantly affect R&D activity conducted by small high-technology firms.[36] Larger firms may be able to produce cash flows above investment needs and generally have better access to capital markets. Smaller or younger firms in high-technology sectors have the additional burden of being engaged in riskier technological activities with unproved market records.

SBIR. The Small Business Administration (SBA) has a key role helping small and disadvantaged firms obtain financing, government R&D contracts, or technology transfer opportu-

[35]Sections 3705, 3706, and 3707 of Title 15, United States Code.

[36]In particular, R&D has a stronger relationship with the permanent or long-term component of cash flows. For example, permanent funding is required for R&D personnel, who are costly to hire and train (Himmelberg and Petersen 1994).

Figure 4-20.
Participation of public organizations in industry RJVs: 1985–2000



RJVs = research joint ventures

SOURCE: Based on data from Link, A. 2001. *Federal Register Filings: The 2000 Update of the CORE Database.* Report submitted to the National Science Foundation, Arlington, VA.

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nities, and providing technical support for R&D and commercialization activities.[37] A major tool of this policy objective is the Small Business Innovation Research (SBIR) program, created by the Small Business Innovation Development Act of 1982 (Public Law 97-219), coordinated by SBA. Ten years into the program, it was reauthorized with an emphasis on commercialization "as an explicit criterion when evaluating proposals" (Public Law 102-564).[38] The same bill created the Small Business Technology Transfer (STTR) program, a smaller program emphasizing cooperative R&D and technology transfer.[39]

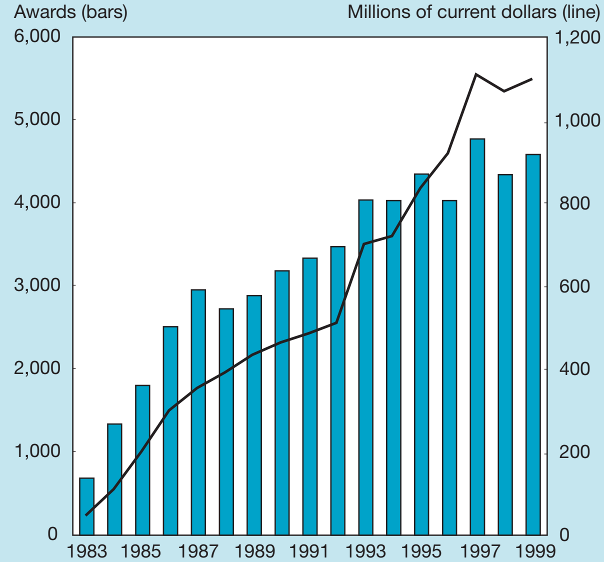
The programs do not represent separate funding from SBA but, rather, redirect other Federal agencies' R&D funds to small firms (those with 500 or fewer employees). Projects are administered by participating agencies. Specifically, Federal agencies with extramural R&D obligations above $100 million must set aside a fixed percentage of such obligations for SBIR projects. This set-aside has been at 2.5 percent since FY 1997. To obtain this Federal funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made. If the concept shows further potential, the company can receive a Phase II grant of up to $750,000. In Phase III, the innovation must be brought to market with private-sector investment and support; no SBIR funds may be used for Phase III activities.

From 1983 to 1999, SBIR awarded $9.7 billion to over 55,000 projects. Projects included research in computers, information processing and electronics, materials, energy, environmental protection, and life sciences. In 1999, the program awarded $1.1 billion in R&D money to 4,590 projects. (See figure 4-21.) Ten agencies participated in FY 1999; DOD is the largest participant with $514 million (47 percent), followed by HHS with $314 million (29 percent), funding 1,962 (43 percent) and 1,236 (27 percent) projects, respectively, in 1999. (See appendix table 4-36.) Given the design of the program, its overall size and agency participation mirror the size and composition of the Federal extramural R&D budget.

On average, approximately three-fourths of the awards are for Phase I, but they use only about 30 percent of the funds. There are many more projects in the first exploratory phase because only the most worthy projects (in terms of technical and commercialization prospects) move to the second phase. At the same time, these second-phase projects have used an increasing share of the funds from all agencies combined. This reflects an increase in dollars per Phase II project from the low $300,000s at the beginning of the program to $635,000 in 1999.[40]

The geographic distribution of SBIR awards reflects the overall concentration of total Federal R&D funding. In particular, in FY 1998, the top five states (California, Massachusetts, Virginia, Maryland, and Colorado) received one-half of both awards and SBIR dollars. Several agencies have used the SBIR program in conjunction with other outreach programs to increase participation of states with traditionally low levels of Federal R&D funding. For example, according to the U.S. GAO (1999b) report, NSF has used its Experimental Program to Stimulate Competitive Research (EPSCoR) to increase assistance to SBIR participants in EPSCoR states and the Commonwealth of Puerto Rico.[41] Assistance includes a "Phase Zero" award to help in the preparation of SBIR proposals.

Figure 4-21.
Growth in SBIR awards and funding: 1983–99



SBIR = Small Business Innovation Research

See appendix table 4-36. *Science & Engineering Indicators – 2002*

STTR. The STTR program pairs eligible small businesses with either nonprofit institutions or an FFRDC to perform joint R&D projects. The purpose is to leverage the technical resources of these research institutions (mostly universities) with small businesses for technology development, transfer, and commercialization. Participating small businesses must perform at least 40 percent of the work and be in overall control of the project. The program is structured, much like the SBIR program, in three phases. The first phase studies technical and commercial feasibility with funding not to exceed $100,000 for one year; further development occurs in the second phase with a maximum of $500,000 in funds over two years. In the last phase, the participants engage in commercial applications with no Federal STTR funds.

Five Federal agencies with more than $1 billion in extramu-

[37]See text of Public Law 106-554, December 2000. For analysis of small business research programs as public venture capital programs, see Lerner and Kegler (2000) and references therein.

[38]See also U.S. GAO (1999a).

[39]SBIR was reauthorized in December 2000 by the Small Business Reauthorization Act of 2000 (Public Law 106-554) through FY 2008 (September 30, 2008). A bill to reauthorize the STTR program, scheduled to expire in September 2001, was introduced in the Senate in May 2001 and placed on the Senate Legislative Calendar in late August 2001 (S. 856, 107th Congress).

[40]The average dollar amount per project is $61,800 for Phase I and $434,370 for Phase II over the life of the program through FY 1999.

[41]The states are Alabama, Arkansas, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, and Wyoming.

ral R&D participate in the program: DOD, NSF, DOE, NASA, and HHS. Since FY 1996, the required set-aside has been 0.15 percent compared with 2.5 percent for the SBIR program.[42] From FY 1994 to FY 1999, the STTR program has awarded more than $300 million to more than 1,700 projects. In 1999, STTR awarded $65 million to 329 projects. (See appendix table 4-37.) Three-fourths of the projects were in Phase I. The largest participant by far is DOD. The majority of the research institutions participating were universities (283 of 329, or 86 percent). The remainder were divided between FFRDCs (22) and hospitals and other nonprofit organizations (24).[43]

International Private and Public Collaborations

International Business Alliances

In 2000, 574 new technology or research alliances were formed worldwide in six major sectors: information technology (IT), biotechnology, advanced materials, aerospace and defense, automotive, and (nonbiotech) chemicals, according to the data available from MERIT-CATI (Hagerdoon 2001). Over the past two decades, the formation of international technology alliances has grown considerably. In particular, there were 6,477 technology alliances formed between 1990 and 2000 compared with 3,826 over 1980–89. However, international alliances peaked at 812 in 1995, the same year, domestic collaborations peaked in the CORE database. This is not surprising given the significant role of alliances involving U.S. companies. (See figure 4-22.)

The majority of the alliances involved companies from the United States, Japan, and countries of Western Europe. Fully 80 percent (5,187) of the 1990–2000 alliances involved at least one U.S.-owned company (see text table 4-12), compared with 64 percent in the 1980s. At the same time, European firms participated in 2,784 technology alliances. Japanese companies were involved in 910 partnerships, down slightly from the earlier period.[44] The dominance of U.S. companies in this database is also clear by noting that among the alliances involving at least one U.S. company, the share of alliances involving *only* U.S. firms increased from 37 percent in the 1980s to more than 50 percent in 1990–2000. (See figure 4-23.) On the other hand, European and Japanese companies engaged in more interregional collaborations compared with U.S. companies. As discussed below, these geographic patterns were driven by IT and biotechnology R&D activity.

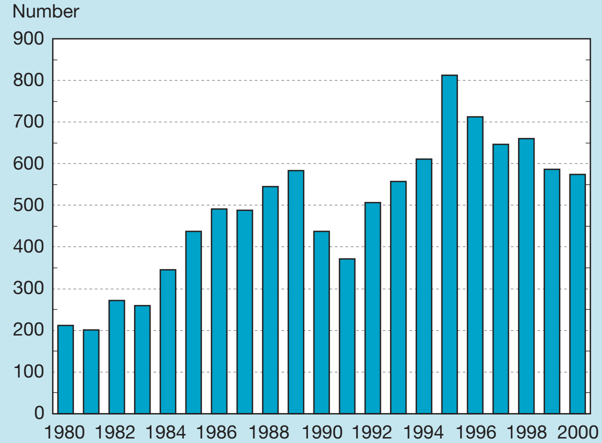
Technology Focus. The share of biotechnology partnerships reached an all-time high of 35 percent in 2000 (199 of 574), continuing an increasing trend that began in 1991. (See figure 4-24.) Furthermore, this is the first time that biotech alliances have outnumbered IT partnerships in any given year in the database, dating back to the 1960s. In 2000, there were 184 (32

[42]The initial set-aside percentages were 0.05 percent in FY 1994 and 0.1 percent in FY 1995.

[43]For a survey of companies receiving STTR awards see U.S. GAO (2001b and 2001c).

[44]As discussed previously, technology partnerships announced in non-English publications, such as those based in Asia, are likely to be undercounted.

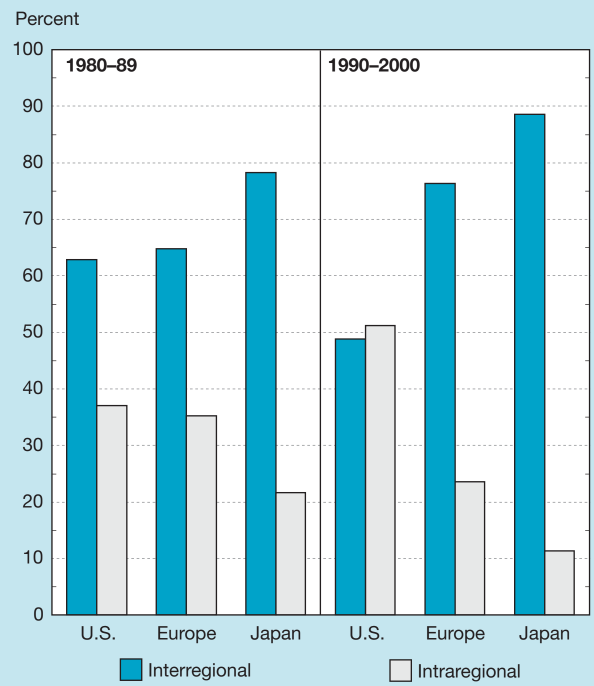
Figure 4-22.
International strategic technology alliances: 1980–2000



NOTE: Data are annual counts of new international strategic technology alliances.

See appendix table 4-39. *Science & Engineering Indicators – 2002*

Figure 4-23.
Shares of international strategic technology alliances: 1980–89 and 1990–2000



NOTES: Interregional share refers to the share of alliances formed by companies from different countries or regions. Intraregional shares consider only alliances among companies from the same country or region. Total alliances: 1980–89: U.S. = 2,445; Europe = 1,904; Japan = 1,073. 1990–2000: U.S. = 5,187; Europe = 2,784; Japan = 910.

See text table 4-12 and appendix table 4-39.

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Text table 4-12.
International strategic technology alliances: 1990–2000

Region	All alliances	Information technology	Biotechnology	All other technologies
		Counts		
All regions	6,477	2,687	1,553	2,237
USA-Europe	1,654	536	525	593
USA-Japan	511	292	82	137
USA-Others	364	158	71	135
Europe-Japan	239	92	37	110
Europe-Others	234	64	49	121
Japan-Others	56	30	6	20
Intra-USA	2,658	1,299	629	730
Intra-Europe	657	169	147	341
Intra-Japan	104	47	7	50
		Regional shares (percentages)		
All regions	100	100	100	100
USA-Europe	26	20	34	27
USA-Japan	8	11	5	6
USA-Others	6	6	5	6
Europe-Japan	4	3	2	5
Europe-Others	4	2	3	5
Japan-Others	1	1	0	1
Intra-USA	41	48	41	33
Intra-Europe	10	6	9	15
Intra-Japan	2	2	0	2
		Technology shares (percentages)		
All regions	100	41	24	35
USA-Europe	100	32	32	36
USA-Japan	100	57	16	27
USA-Others	100	43	20	37
Europe-Japan	100	38	15	46
Europe-Others	100	27	21	52
Japan-Others	100	54	11	36
Intra-USA	100	49	24	27
Intra-Europe	100	26	22	52
Intra-Japan	100	45	7	48

SOURCE: Based on data from the Cooperative Agreements and Technology Indicators (CATI) database, Maastricht Economic Research Institute on Innovation and Technology (MERIT), Maastricht, the Netherlands.

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percent) new IT partnerships, less than the 225 partnerships in 1999. The number of new IT alliances peaked in 1995 at 338, reaching a maximum share of 55 percent in 1991. More important, the combined shares of these two technologies increased from 55 percent in the 1980s to 66 percent in the 1990s.

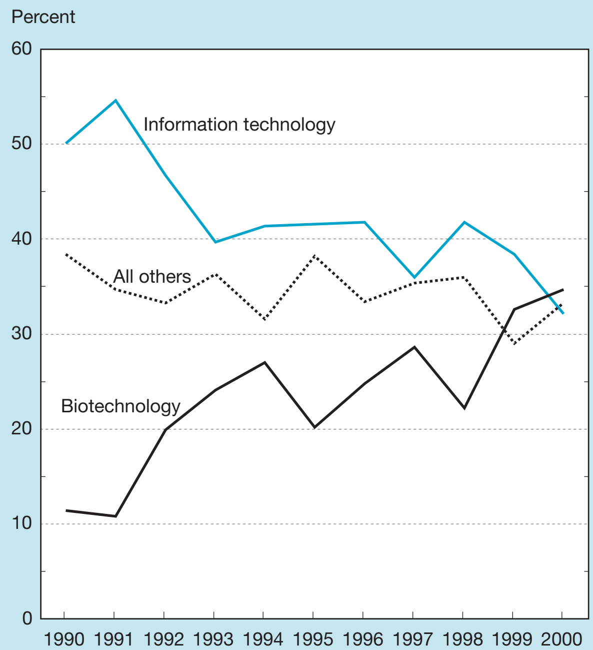
The United States and Europe were prime locales for biotechnology alliances during the 1990s, attracting the interest of venture capital and stimulating high-profile projects such as the decade-long effort to map the human genome. Of the 1,500 biotechnology alliances in the past decade, 41 percent involved U.S. companies only and another 34 percent involved pairings of U.S. and European companies (see text table 4-12). This partnering is likely to intensify in coming years as biotechnology startups and pharmaceutical firms collaborate with instrument, software, and bioinformatic companies for the next research step dubbed “proteomics,” which involves mapping the structure and function of proteins based on gene expression databases (Hamilton and Regaldo 2001).

Interregional IT alliances have become less frequent in the MERIT-CATI database. In 1990–2000, a majority of IT partnerships (56 percent) were within countries or regions (United States, Japan, or the European region), as opposed to alliances across regions (44 percent). This compares with an even split between these two types of IT alliances in the 1980s. Furthermore, U.S.-only partnerships represent about one-half of IT alliances, up from 29 percent in the 1980s.

Government-to-Government Cooperation

Nation-to-nation cooperation constitutes a special case of international research collaboration. In addition to the rationale for collaborative projects discussed earlier, these projects often have an added dimension in terms of foreign policy objectives and security issues. Some so-called megaprojects are characterized by extremely high costs, key national stakes, and often multiple international stakeholders. Forms of international government collaboration include

Figure 4-24.
International strategic technology alliances, by technology shares



See appendix table 4-39.

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joint construction, operation, and use of large facilities for research or exploration (e.g., space and nuclear physics) and joint research activities.[45]

At least three organizational forms of government-to-government S&T collaboration can be identified. An individual U.S. agency may collaborate with sister agencies abroad to pursue common R&D interests, leveraging funds and technical expertise. U.S. agencies may also form a research umbrella to work together among themselves and then engage in joint activities with overseas organizations as needed. Governments also may use international organizations to advance scientific or technical objectives, often in conjunction with complementary national goals. See sidebar, "Collaborative R&D Projects in Selected International Organizations."

Looking at agency-specific activities, the U.S. GAO (1999b) estimated that 575 international S&T agreements existed between seven U.S. agencies (DOE, NASA, NIH, NIST, NSF, National Oceanic and Atmospheric Administration (NOAA), and the State Department) and other countries in FY 1997. However, not all of these S&T agreements included cooperative R&D activities. At the same time, cooperative R&D projects also occur outside such formal international interagency agreements. Funding data are particularly scarce. A report by RAND's Science and Technol-

[45]Projects in this category can cost as much as several billion U.S. dollars over many years of planning and development. See Boesman (1994) and U.S. Congress, Office of Technology Assessment (1995).

Collaborative R&D Projects in Selected International Organizations

In addition to national agencies, governments also use international organizations to promote, study, and coordinate scientific collaboration. The following is a sample of scientific activities coordinated by international organizations.

- **Global Forum on Agricultural Research.** The activities of the Global Forum on Agricultural Research (GFAR) include the promotion of research partnerships in agricultural R&D as well as the exchange of scientific and technical information. GFAR is fostering global and regional research partnerships in the areas of biotechnology, plant genetics, biodiversity, agroecology, and natural resources management (website: <http://www.egfar.org/>).

- **North Atlantic Treaty Organisation (NATO) Science Program—Cooperative Science and Technology Program.** This program supports conferences, workshops, and collaborative grants for scientists of NATO and some partner countries. Four scientific areas are covered: life sciences, physics and engineering, environmental and earth sciences, and security-related civil S&T (website: <http://www.nato.int/science/e/cst.htm>).

- **Organisation for Economic Co-operation and Development (OECD) Global Science Forum.** The OECD's Global Science Forum identifies opportunities for international cooperation in basic scientific research. The forum establishes special- purpose working groups and workshops to perform technical analyses. Activities include workshops on structural genomics, compact ultrahigh-power lasers, a consultative group on high-energy physics, a working group on neuroinformatics, and a task force on radio astronomy and the radio spectrum (website: <http://www.oecd.org >).

- **World Health Organization's Special Program for Research and Training in Tropical Diseases.** The World Health Organization's (WHO's) Special Program for Research and Training in Tropical Diseases was established in 1975 and is cosponsored by the United Nations Development Program, the World Bank, and WHO. The program supports global efforts to combat a portfolio of major diseases affecting developing countries (website: <http://www.who.int/tdr/about/mission.htm>).

ogy Policy Institute tries to fill this gap by compiling R&D spending data on international cooperative projects sponsored by U.S. agencies (Wagner, Yezril, and Hassell 2001).

The RAND report finds that approximately $4.4 billion in R&D spending by Federal agencies involved a significant international content in FY 1997 compared with $70 billion in total Federal obligations for R&D work in that year. The vast majority of the spending involves scientist-to-scientist collaboration in joint research projects. Technical support to aid a foreign country was a distant second. The largest spending for binational R&D cooperation was identified in projects involving Russia, Canada, the United Kingdom, Germany, and Japan. Spending in collaborative R&D with Russia increased considerably since the dissolution of the Soviet Union, especially in aerospace and aeronautics. Other scientific and policy interests in this area of the world include containing nuclear materials and aiding the transition of Russian scientists from weapons to civilian research.

Spending in aerospace and aeronautics accounted for more than one-half of the U.S. R&D dollars committed to a single field of collaboration across all countries. Biomedical and other life sciences, engineering, and energy fields also received significant international support. In part, the preeminence of aerospace research in international research spending is due to the disproportionate share of NASA in these statistics, fully $3.1 billion of the reported $4.4 billion, including funding for large multicountry projects such as the International Space Station and the Earth Observing Satellite System. Undoubtedly, international R&D support provided by other agencies is somewhat undercounted. For example, DOD figures reported at $263 million are likely to be an underestimate due to data validation problems, according to RAND. NIH, NSF, and DOE also perform key international work with projects in human genetics, infectious diseases, geosciences, and other basic research and energy sciences.

In another approach, U.S. agencies have formed interagency research groups that subsequently pursue international activities. For example, the U.S. Global Change Research Program (USGCRP), in place since 1989, studies climate change and Earth ecosystems and performs some of its research and data gathering on an international basis.[46] The program authorized research funds of $758 million in FY 2000 from NASA, NSF, DOE, NOAA, USDA, and other agencies (Executive Office of the President 2001). Another $937 million was authorized in support of NASA's development of Earth-observing satellites and related data systems as part of USGCRP activities. (For a summary of recent efforts to more fully integrate the use of collaborative activities in the international S&E arena, see sidebar, "The NSB Task Force on International Issues in Science and Engineering.")

[46]For a description of international activities of the program, see <http://www.usgcrp.gov/usgcrp/links/relintpr.html>.

The NSB Task Force on International Issues in Science and Engineering

The National Science Board (NSB) is responsible for monitoring the health of the national research and education enterprise. In recent years, the importance of science and technology in the global context has grown. As a result, both private sector and government cooperation in international science and engineering have become more prominent.

The NSB took note of these developments in preparing its strategic plan (NSB-98-215), in which it observed that one of the most important challenges confronting the United States is how to deal with science and engineering in the global context. The National Science Board expressed the need for a fresh assessment of the roles and needs of science and engineering in the international arena, and for a coherent strategy that supports a productive relationship between scientific and foreign policy objectives.

The Board subsequently established the Task Force on International Issues in Science and Engineering to undertake this assessment. The task force was charged with examining the Federal policy role and the institutional framework that supports international cooperation in research and education, as well as NSF's leadership role in international S&E in the 21st century. The task force has organized symposia, workshops, and panel discussions with a broad array of experts and stakeholders and has conducted an extensive review of relevant policy documents and reports. Two interim reports will be followed shortly by a comprehensive National Science Board report on international science and engineering.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. The relative strength of a particular country's current and future economy and the specific scientific and technological areas in which a country excels, are further revealed through comparison with other major R&D-performing countries. This section provides comparisons of international R&D spend-